

SURVEY DATA COLLECTION ASSOCIATED WITH AN AML EMERGENCY PROGRAM

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ABSTRACT

Unplanned sag subsidence affects structures of all kinds throughout the coal mining regions of the world. The writers have been involved with investigating and monitoring sag subsidence events in the state of Illinois since 1980 and have found that surveying can provide important data yielding insight on the behavior of the subsidence event. Detailed survey information facilitates subsidence research of ground movements, aids in evaluating structural response and is useful in determining the optimum time for structural repair. Survey data quality is generally limited by factors such as monument design, monument spacing, frequency of measurement, quality of survey equipment, and proper survey technique. The main problem encountered in establishing techniques for the monitoring of a sag subsidence event is the trade-off necessary between physical constraints and time constraints. Since Illinois Department of Natural Resources- Abandoned Mined Lands Reclamation Division (AMLRD) personnel typically become involved early in the development of a subsidence event, we have the unique opportunity to investigate early ground movements as well as the ability to continue monitoring the ground movements through completion. This paper is meant to provide an overview to the survey techniques utilized by the AMLRD in those investigations designed to collect long term ground movement data associated with coal mine subsidence.

INTRODUCTION

The use of precision level surveys as means of monitoring structural damage resulting from unplanned coal mine sag subsidence has been an important part of the Illinois AML Emergency Program since its inception nearly 25 years ago. As our understanding of sag type subsidence evolved so did our survey technique. We know that at onset, large and rapid ground movements over a definable area are common to subsidence. Further, subsidence related ground movements are by nature continuous and continuously decreasing in rate through time. Based on empirical estimates, nearly 40 to 60 percent of the total ground movement typically occurs within the first few days following the onset of subsidence movements. Therefore, the elapsed time between the onset of subsidence and the first response by qualified investigators represents a significant magnitude of movement that goes unmeasured, and in many instances, is lost. The primary concern of the AMLRD is to protect the public from mine related problems that constitute an immediate threat to the public health, safety, or general welfare (from Public Law 95-87). Because we typically become involved early in the development of a subsidence event, we have the unique opportunity to investigate early ground movements as well as the ability to continue monitoring the ground movements through completion. As the AMLRD has become more responsive to the needs of the public, greater expectations have been placed on the program to provide the expertise that would otherwise be generally unavailable to the property owner or

public entities such as local government. The collection and analysis of survey data, along with other information, has enabled the personnel of the AMLRD to develop a better understanding of the behavior of subsidence events, how they vary regionally, and to utilize this information to the benefit of the public.

Throughout the last 20 years the investigators have constantly sought to improve the cost effectiveness, efficiency, and integrity of the data that is collected at subsidence events. During the early 1980's when the Illinois emergency program was first developing, our involvement at a site would have been limited from a few months up to a year. Survey information was collected with the intent to measure only large magnitude ground movements. Therefore survey monuments were considered to be temporary and were chosen based on ease and speed of installation. It was determined that by making slight modifications in our initial surveying practices, that we could substantially improve both the overall quality and extend the longevity of the survey net. As data was collected on various projects, the technique was refined to improve the overall effectiveness of the process.

The main problem encountered in establishing techniques for the monitoring of a sag subsidence event is the trade-off necessary between physical constraints and time constraints. These are interdependent and a change in one affects the performance of the other. Some examples of physical constraints include survey equipment quality, monument design, monument location, and survey technique. In addition to physical constraints, time constraints present complications in dealing with the dynamic movements characteristic of subsidence events. Locating, installing, and surveying of monuments for subsidence investigation would be straightforward, if not for time constraints. Monuments could be surveyed using high quality equipment, under optimum surveying conditions (wind, temperature, humidity and available light) with a predetermined number of equipment setups all designed to keep error to an absolute minimum while providing the maximum amount of data.

The procedures we have developed have been designed to address time related problems associated with the collection of survey data. In the early stages of a subsidence event, it is difficult to establish and collect survey information of the same quantity and quality, as can be collected 6 months into an event. Another complication is related to settlement rate and longevity of a subsidence event. Some subsidence events are continuing to settle more than a decade after onset. The challenge in monitoring these types of problems is maintaining monument integrity. Loss of monuments due to damage becomes increasingly problematic when monitoring subsidence ground movements lasting a decade or longer. Thus, when measuring subsidence related ground movements, it is necessary for the investigator to adjust procedures to accommodate the different challenges inherent with subsidence to ensure quality data throughout the monitoring period. These procedures provide a baseline that is often supplemented with other measurements for the purpose of investigating certain characteristics of a subsidence event.

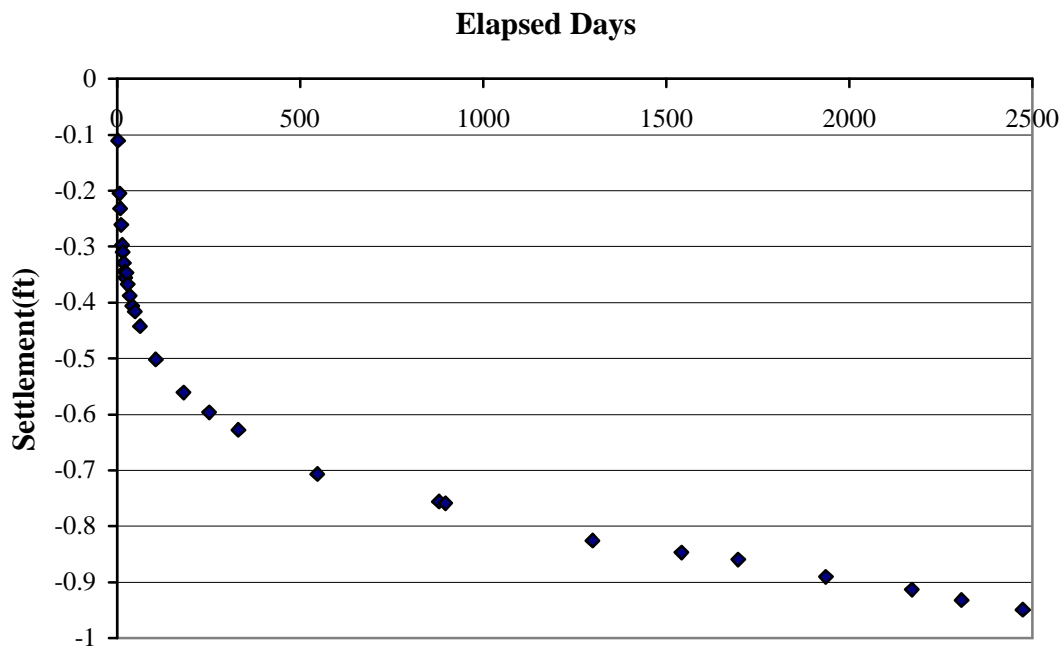
GENERAL TECHNIQUES

Once subsidence begins, the ground drops continuously until movements cease. In the early stages, large and rapid settlements along with differential movements, commonly characterize a subsidence event. This places a challenge on the survey techniques that are necessary to collect a snapshot of the settlements. As the subsidence event gets older, the rate of movement decreases until differential movements during the course of a single survey have little

effect on data integrity. Toward the end of the event, the magnitude of subsidence is sufficiently small so that it becomes very difficult to differentiate subsidence related ground movement from measurement error or soil effects. Varying aspects of the survey such as monument design, layout, timing, and procedures accommodates these differing conditions.

Generally, we have found that surveys using 2nd order or better equipment yield the best value for investigation and analysis. For obvious reasons, a first order instrument yields the greatest precision in surveys. However the requirements in maintaining 1st Order precision surveys increase the time and cost necessary to conduct a full survey. The increased precision is more than offset by the error introduced by the ground movements which take place during the early stages of an event. In other words, the error introduced by the subsidence ground movement may yield 2nd Order or lower error results even using 1st order equipment and techniques. The net result is a less accurate survey. The higher the order of the survey though, the more useful the data, especially in the latter stages of an event when settlements rates are small and approaching zero. We employ equipment and techniques that are consistent with 2nd order survey requirements. The AMLRD uses both a Wild NA2002 (2nd order instrument) and a Wild NA 3003 (1st Order instrument) digital level for surveying. We have found that the use of either instrument with a second order staff in conjunction with our survey techniques consistently yields accuracy approaching 1st order.

Figure A illustrates the settlement of a monument through time and is typical to many events monitored by the AMLRD. From the figure it can be seen that during the initial stages of the event, survey measurements were taken frequently when settlement rates were large. Plotting the elevations in this manner allows the researcher to confirm that the rate of settlement is diminishing. Estimates of future settlement can thus be made and the time between successive surveys gradually increased until they are taken on an annual basis.



Sag Type Subsidence: Time vs. Settlement

Figure A

NETWORK DEVELOPMENT

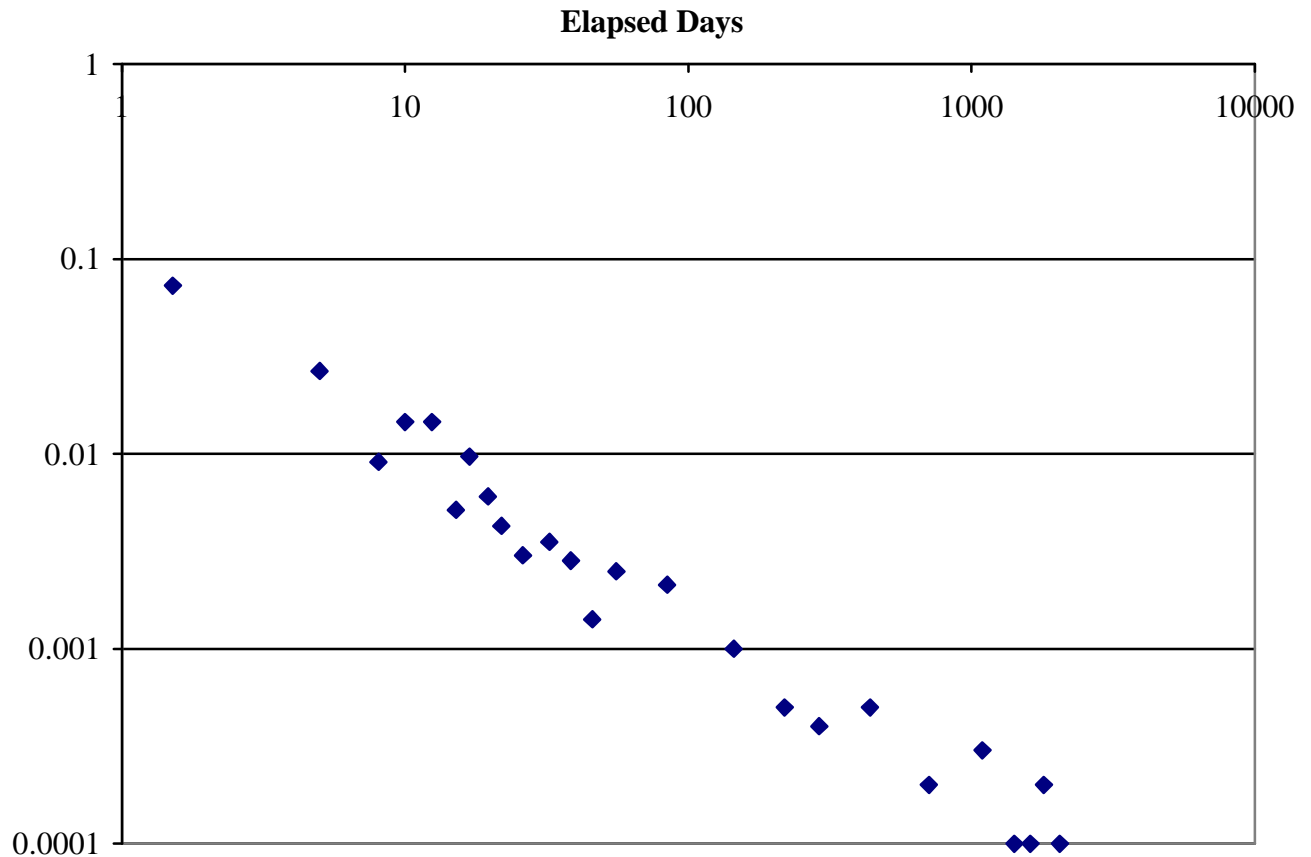
During the early stages of a subsidence event, ground movements within the sag can be sufficiently large in magnitude and rate, whereby measurable change in surface elevation can occur within a few hours. As the ground drops, there is a change in shape. In order to characterize the shape of the ground surface, it is necessary to measure all the points collectively, as close as possible to the same point in time. In order to determine the rate of settlement, it is necessary to measure all the points as frequently as possible. These competing tasks are difficult to accomplish and can be additionally complicated if the subsidence event is large, requiring stationing the leveling instrument within the subsiding area, and requiring a substantial amount of time to complete a survey. The amount of error resulting from the instrument settling during a survey can be significant and is indicated in the value calculated for the Standard Error of Closure. These problems are typical of many subsidence events in Illinois.

There are different approaches that can be applied to address the problems described above but they involve a trade off between measuring the shape of subsidence and the rate of subsidence. One solution would be to forego measuring the shape of the subsidence movements and concentrate solely on the rate of movement. This could easily be accomplished by measuring one point at or near the center of the event until settlement rates have negligible impact on survey accuracy. Such an approach has obvious shortcomings since the large movements that occur early in the event can be detrimental to structures. These movements also tell us the most about the shape of the event. For these reasons, it is beneficial to conduct a survey that includes a sufficient number of points to describe the shape of ground movement and to acknowledge that closure error may be greater than would be considered acceptable in later surveys. This error is proportionately a small percentage of the measured movement and is insignificant in the overall analysis. Knowing the source of potential error, however, gives us the opportunity to minimize the magnitude. This is accomplished by controlling the survey technique and physical characteristics of the monuments.

When establishing a survey network early in the development of a subsidence event, it is worthwhile to design a network that meets immediate data objectives and is expandable for long-term objectives. Ideally, monuments would be positioned so that instrument stationing maximizes the speed of surveying the network, thereby minimizing the error subsiding ground introduces on the instrument. Usually increasing the density of monuments through time and choosing locations that keep the number of required setups to a minimum can accomplish this. Additionally the instrument can be stationed as far as possible from the center of the event where settlement rates are largest. Typically, our first few surveys of a subsidence event are designed to minimize the amount of time the instrument is within the event. Although this may require an additional setup or two, it is a small tradeoff to maintain closure integrity. However, too many setups can increase the time to complete a survey and introduce error associated with the settlement of the instrument while within the limits of the sag.

Figure B shows a plot of survey data that illustrates the rate of settlement typical to many events. After about a week to ten days, settlement rates have decreased to a manageable level. Since each event behaves uniquely, this plot is only considered representative of expected decline in settlement rate. It does, however, provide a guideline, in the absence of any specific survey data, on when to adjust survey procedures.

When first establishing a survey network for a new event, we attempt to define the limits of the subsidence event. We then utilize this information to determine the best location of the survey lines to achieve our desired cross-section profiles. We have found that level survey data is most useful when monuments are established in a ‘plus’ pattern where the lines intersect near the center of a sag. This pattern allows us to construct cross-sections of the subsidence event along



Settlement Rate Example

Figure B

which we can calculate the maximum settlement, slope and curvature and apply it to critical structures affected by the event. A temporary monument line will usually be established expediently. If it is at all possible, we attempt to incorporate our initial temporary monuments coincident with or parallel to our final profiles.

MONUMENTS

Monument design can be divided into two types, temporary and permanent. Temporary monuments tend to be those that are convenient to install but provide information that is useful for a limited time. In general, measurement error increases through time when using a temporary type monument. Permanent monuments tend to provide meaningful data for long periods of time

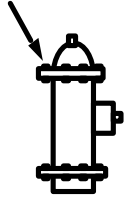
but may be more difficult and/or costly to install. Often it is necessary to install a combination of types and gradually replace or supplement temporary monuments with permanent monuments. It is desirable to keep the replacement of monuments to a minimum to ensure data integrity. Typically it is necessary to install a minimum number of monuments in order to roughly characterize the event. Additional monuments are sometimes added on a time permitting basis to more fully characterize and quantify ground and structural movements.

Several monument designs have been found to provide acceptable survey results. Temporary benchmarks, located outside the affected area, can include any of the following: drop-in anchors set into building foundations or power poles; fire hydrant cap bolts; large spikes driven into a wood utility poles; frost protected rebars; and property corner stakes. Temporary monuments located within the subsiding area may include those described above in addition to short wooden or plastic stakes, PK nails driven into concrete or asphalt surfaces, paint markings on a hard surface, or pencil marks on an interior floor. Figures C and D illustrate the design and functionality of temporary and permanent survey monuments.

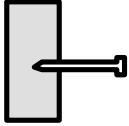
As the subsidence event develops and settlement rates decrease, there is more time for personnel to establish a permanent survey grid. During this time, the initial survey points are supplemented with more permanent monuments. Typically, frost protected re-bars are installed for the final bi-directional pattern across the event. Generally, these monuments would be placed at intervals of approximately 10% of the mine depth. We typically use intervals of 5, 7, or 10 meters (ranges 6- 15 % mine depth) depending on the characteristic of the event. The frost protected rebars are constructed as described in Figure D and can be installed relatively quickly and with little intrusiveness on the property owners. A single monument can be installed in less than 5 minutes with favorable soil conditions. When possible, the survey lines are extended completely through the subsidence event so that each line terminates outside the affected area. This aids in defining the boundary of an event and provides a means to check the quality of the survey data.

Permanent benchmarks are usually established during this time. The location of the benchmark is based on finding a convenient location at the surface, with a low probability of disturbance that also corresponds to the maximum available support at the mine level. We utilize multiple benchmarks surrounding an event to verify stability of all the benchmarks. Typically we install at least two benchmarks outside the affected area on opposing sides of the subsidence event. A third benchmark may be included, particularly if multiple events are being monitored in the same general vicinity, or if we suspect that the event may increase in size. We prefer to keep the distance between the benchmark and affected area to a minimum for several reasons. First, error increases with survey distance. Second, since many of the mines in Illinois are quite large, the nearest non-mined area may be several miles away from the project site. Finally, by keeping the survey distance to a minimum, we can survey the site more frequently and at a lower cost.

Benchmarks are typically constructed as either 5-foot frost protected rebars or 20-foot long, frost protected deep benchmarks. The deep benchmarks are constructed with a recessed and protected top as shown in Figure D. Other investigators have utilized monument constructions of similar types, but all are designed to minimize adverse soil effects and resist frost related movements. If a 20-foot benchmark is constructed, it is common practice to also install a 5-foot



Fire hydrant cap bolt - typically a bolt is selected in the top flange and described in the survey notes for reference and marked with paint. Demonstrates good long term integrity and average long term accuracy. Maximum lifespan - decades.



A large nail such as a 40d or 60d driven into a wood power pole. Demonstrates fair long term integrity and poor long term accuracy. Maximum lifespan - several years under favorable conditions.



Property corner stake- these are typically 1/2" rebars or 1/2" pipe. Demonstrates good long term integrity and fair long term accuracy. Maximum lifespan - decades.



Wood/Plastic stake - these are typically 1"x2" or 2" x 2" and made of pine, spruce, or oak if wood, 1/2" or 3/4" PVC pipe if plastic. Demonstrates poor long term integrity and poor long term accuracy. Maximum lifespan - 6 to 12 months.



PK nails - These are typically 1.5" to 2" long and are driven into pavement; generally asphalt or macadam. PK nails can yield extremely variable results and are significantly dependent on their environment and installation. Some may provide good results for more than a decade and others may not last 1 month. Demonstrates good long term integrity (with proper installation) and average long term accuracy. Maximum lifespan - months to decades.



Floor marks - These are marks which are made on floors, usually interior where other types of monuments may be unacceptable. Demonstrates average long term integrity and average long term accuracy. Maximum life span - years (with periodic maintenance)

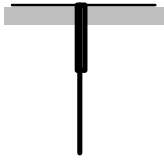


Paint marks - This can simply be a small paint spot which is sprayed on a road or other hard surface. It is very quick to install and can provide reasonable results during the early phases of a subsidence event. Demonstrates poor long term integrity and poor long term accuracy. Maximum lifespan - 6 to 12 months

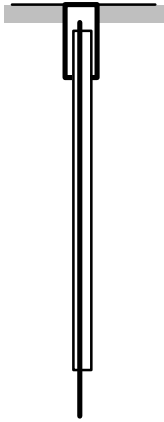
Temporary Survey Monument Types

Figure C

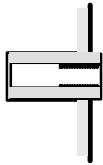
frost protected rebar beside it. Bauer and Van Rosendaal (1992) recommend founding all monuments within the same geological unit to minimize possible differential movements resulting from natural volumetric changes within soil. The five foot and twenty foot frost protected monuments are now used to measure differential movement within the soil that is unrelated to subsidence. We have found the 20 ft. rebars to be only slightly more stable than the 5 ft rebars, but more damage resistant due to their construction. In some instances, deeper monuments may be necessary based on the presence of multiple soil units.



Frost Protected rebars - These points are constructed of 5' rebars which are driven into the ground through a 24" long section of 3/4" CPVC pipe. The points can be installed quickly using a 1" soil sampler to make a hole, placing a precut length of CPVC into the hole and then driving a rebar down through the pipe and leaving it flush with the ground. Demonstrates excellent long term integrity and excellent long term accuracy. Maximum life span - decades.



Frost protected deep benchmarks - These points are constructed of a long steel pipe or rod which is driven into the soil inside a 2" PVC pipe which has been placed to a depth of 10 to 20 feet. The rod is driven several inches below the ground surface and the entire unit is encased in a section of 4" PVC and capped. This type of design is shielded from minor surface damage and most weather effects. Demonstrates excellent long term integrity and excellent long term accuracy. Maximum life span - decades.



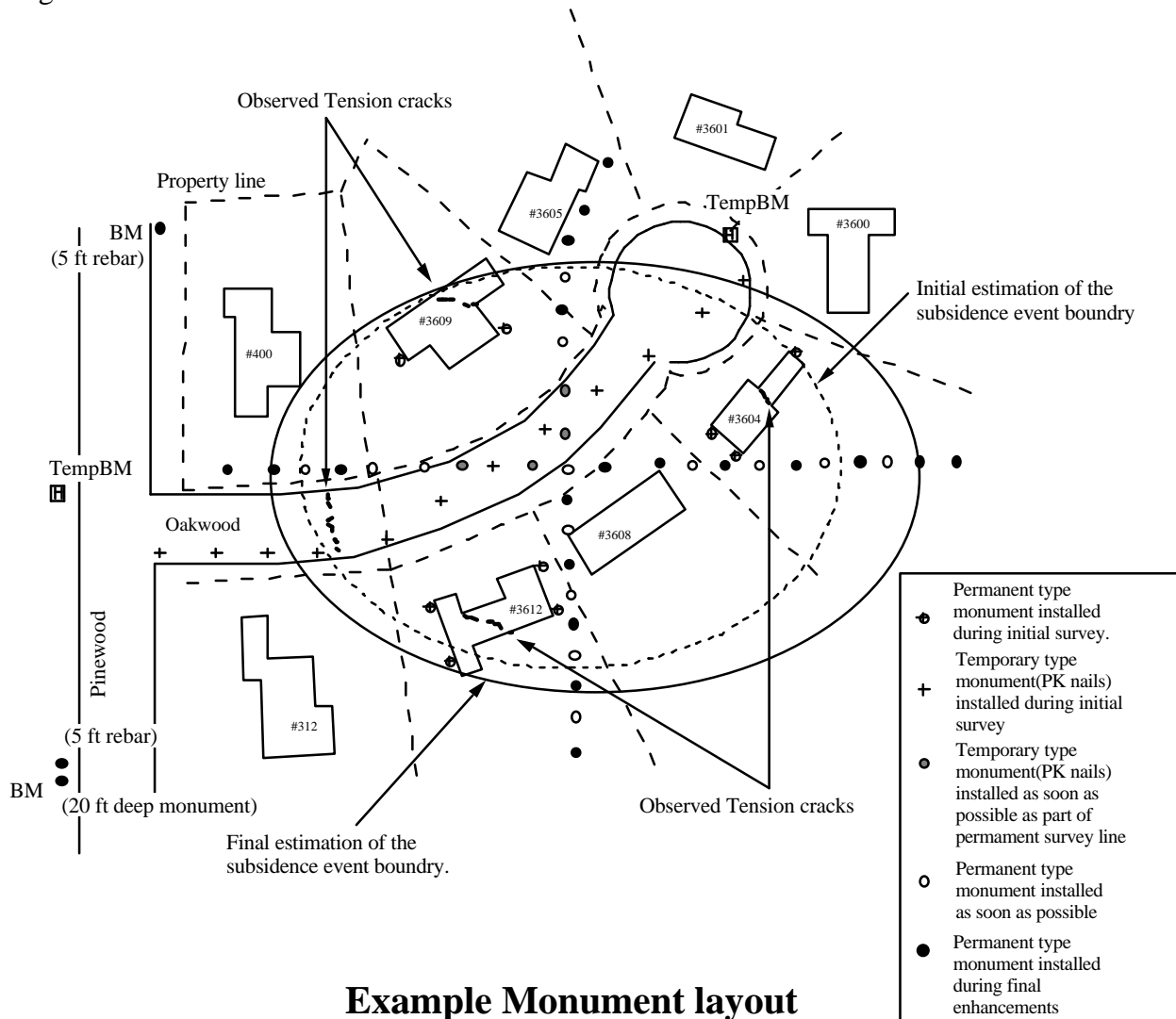
Drop-in anchor, typically 1/2" or 3/8"; Installed by drilling into power poles, light poles, foundations, ect and setting with a punch; this unit is used with a precision manufactured surveyors plug or shoulder bolt which is threaded in for surveying and then removed. The same plug or bolt is used in all dop-ins which have been set. Demonstrates good long term integrity and good long term accuracy when placed into deep founded structures. Maximum lifespan - decades.

Permanent Survey Monuments

Figure D

Figure E illustrates the monument layout for a typical subsidence event. Monuments are initially installed with concern for the following factors: 1) avoidance of subsurface utilities, 2) rate of ground movement, 3) number and location of structures within subsidence event, 4) maximum coverage of monitoring area, 5) minimum installation time, 6) minimum survey time and 7) facilitation of special research objectives. These objectives usually require several different monument designs. PK nails are installed up the road through the center of the subsidence event.

Drop-in anchors are placed into the foundations of critical structures. Fire hydrants on either side of the event are selected to serve as temporary benchmarks for the first few surveys. These monuments enable immediate monitoring and provide information on settlement during the early stages of the subsidence event.



Example Monument layout

Figure E

Once the underground utilities have been located and the first surveys have been completed and analyzed, the permanent monuments as shown in Figure E can be installed. In Figure E, two 5-foot frost protected monuments along with a 20-foot frost protected monument were installed to act as permanent benchmarks. A combination of frost protected rebars and PK nails are installed in the desired plus pattern that extends through the center of the subsidence event. Though not of a permanent design, PK nails are selected for use in the road surface due to lack of a better alternative. Often the size and shape of the event can be determined immediately on investigation. In such instances, having personnel installing permanent monuments while survey crews are measuring the temporary points can reduce the monument network installation

time. The survey crew can then include the new permanent monuments into the survey network as time permits.

COMPLETING THE NETWORK

Typically within the first fifteen to thirty days a majority of the ground movement has occurred. It is during this time that the rate of settlement decreases and field personnel are now able to refine the survey net by installing additional survey points. By this time a large percentage of the survey net has been established. Further, there has been time to inspect all structures and to prepare maps locating both monuments and structures within the subsidence event. Collectively, such information will be used in placing additional monuments. Modifications made both to the monument layout and survey techniques provide a more detailed and accurate view of subsidence movements and allow increased efficiency in data collection. Finally, adjustments are made in survey techniques that employ more stringent and standardized procedures like those that would be used if the ground were considered stable.

The first iteration of frost protected rebar installation involved placing monuments along straight sightlines on intervals that are approximately 10% of the mine depth. The data collected from measurement of these points is utilized to verify whether the existing points 1) are along an orthogonal line whose intersection is at or reasonably near the subsidence center, 2) extend through and beyond the affected area, and 3) adequately describes the event movements. We have found that smaller and sub-critical events typically require closer spacing of monuments. A judgment is made at this time concerning the need and placement of additional points.

Additional monuments may be installed at this time. Such points are usually installed to extend survey profiles, provide specific or detailed information, and to increase accuracy or speed of the survey. Survey lines may sometimes need to be extended because 1) there was insufficient time to place the necessary number of points, 2) the boundary was not chosen correctly, 3) the event is expanding in size, and/or 4) more detailed analysis of boundary conditions are desired. Besides extending monument lines, additional points may be needed to monitor the movement of a structure that is located off the survey lines. If not yet installed, permanent deep benchmarks are established outside the subsiding area at locations considered more stable.

Monument networks are maintained until they are no longer practical (loss of monuments through destruction) or needed (land use change). Some survey stations, particularly temporary points installed during the early phase of the event, may be abandoned at this time, especially if they are susceptible to damage, inconvenient to the property owner or are redundant. Critical monuments are replaced if damaged and additional monuments installed if warranted.

CONCLUSION

Each case presents unique challenges. The procedures outlined above are followed with necessary modifications made to address individual site conditions. A well planned, flexible subsidence monitoring network not only provides benefits to AML programs and researchers studying subsidence mechanics, but also generates real data on regional problems that is helpful in land-use planning and, ultimately, in protecting the public.

REFERENCES

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